

EXHIBIT 023

U.S. Patent No. 8,072,893 (Dielissen & Rijpkema)

“Integrated circuit with data communication network and IC design method”

re’2893 Patent Claim	Samsung Exynos 1280 System on Chip ¹
1. An integrated circuit comprising:	Without conceding that the preamble of claim 1 of the ‘2893 Patent is limiting, the Exynos 1280 system on chip (hereinafter, the “Exynos SoC”) is an integrated circuit.

¹ The Exynos system on chip is charted as a representative product made used, sold, offered for sale, and/or imported by Samsung. The citations to evidence contained herein are illustrative and should not be understood to be limiting. The right is expressly reserved to rely upon additional or different evidence, or to rely on additional citations to the evidence cited already cited herein.

U.S. Patent No. 8,072,893 (Dielissen & Rijpkema)

“Integrated circuit with data communication network and IC design method”

SAMSUNG

Product brief
Create infinite possibilities

Exynos 1280

Highlights
A mobile processor ready for 5G and AI
Advanced ISP and MFC for rich multimedia experience
Powerful octa-core CPU and GPU



5G for all
Exynos 1280 is a mobile processor based on a 64-bit RISC processor. It contains a 5G modem, which is compliant with two types of 5G network (Sub-6GHz and mmWave), as well as all legacy networks. It is built using an advanced 5nm EUV process for high power efficiency.

All-in-one processor for 5G
The Exynos 1280 embedded modem supports both sub-6GHz (Frequency Range

<https://semiconductor.samsung.com/resources/brochure/Exynos1280.pdf>

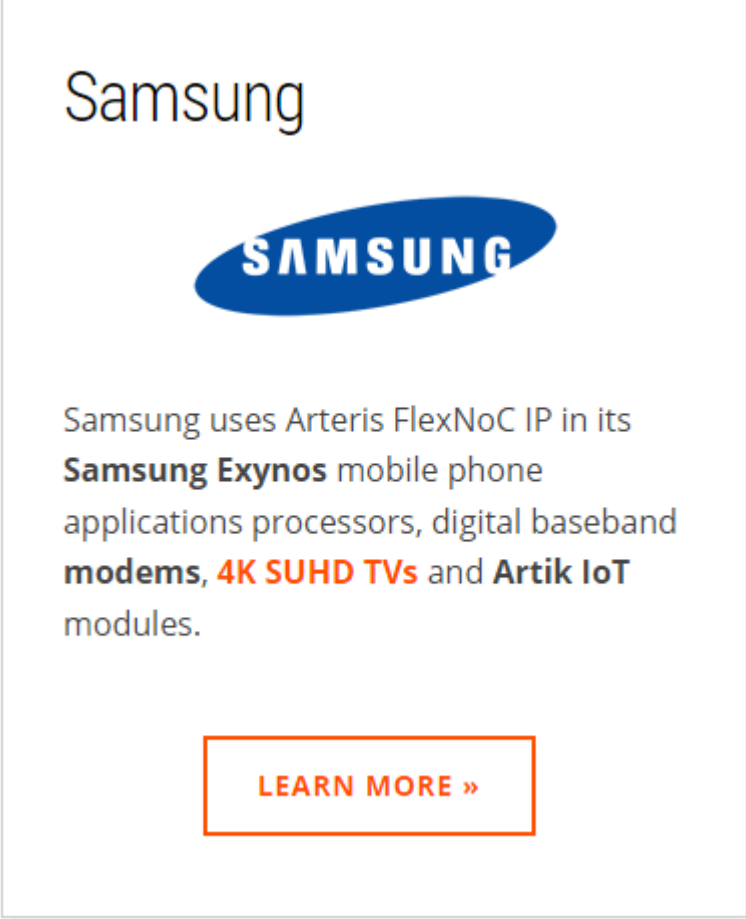
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a plurality of functional blocks; and	<p>The Exynos SoC includes a plurality of functional blocks, for example Arm Cortex-A78 core, Cortex-A55 core, Arm Mali-G68 GPU, and AI Engine with NPU:</p> <h2>Specifications</h2> <table border="1"> <thead> <tr> <th></th><th>Exynos 1280</th></tr> </thead> <tbody> <tr> <td>CPU</td><td>Cortex[®]-A78 x 2 + Cortex[®]-A55 x 6</td></tr> <tr> <td>GPU</td><td>Mali[™]-G68</td></tr> <tr> <td>AI</td><td>AI Engine with NPU</td></tr> <tr> <td>Modem</td><td>5G NR Sub-6GHz 2.55Gbps (DL) / 1.28Gbps (UL) 5G NR mmWave 1.84Gbps (DL) / 0.92Gbps (UL) LTE Cat.18 6CC 1.2Gbps (DL) / Cat.18 2CC 200Mbps (UL)</td></tr> <tr> <td>Connectivity</td><td>WiFi 802.11ac MIMO with Dual-band (2.4/5G), Bluetooth[®] 5.2, FM Radio Rx</td></tr> <tr> <td>GNSS</td><td>Quad-constellation multi-signal for L1 and L5 GNSS</td></tr> <tr> <td>Camera</td><td>Up to 108MP in single camera mode, Single-camera 32MP @30fps</td></tr> <tr> <td>Video</td><td>4K 30fps encoding and decoding</td></tr> <tr> <td>Display</td><td>Full HD+@120Hz</td></tr> <tr> <td>Memory</td><td>LPDDR4x</td></tr> <tr> <td>Storage</td><td>UFS v2.2</td></tr> <tr> <td>Process</td><td>5nm</td></tr> </tbody> </table> <p>https://semiconductor.samsung.com/resources/brochure/Exynos1280.pdf</p>		Exynos 1280	CPU	Cortex [®] -A78 x 2 + Cortex [®] -A55 x 6	GPU	Mali [™] -G68	AI	AI Engine with NPU	Modem	5G NR Sub-6GHz 2.55Gbps (DL) / 1.28Gbps (UL) 5G NR mmWave 1.84Gbps (DL) / 0.92Gbps (UL) LTE Cat.18 6CC 1.2Gbps (DL) / Cat.18 2CC 200Mbps (UL)	Connectivity	WiFi 802.11ac MIMO with Dual-band (2.4/5G), Bluetooth [®] 5.2, FM Radio Rx	GNSS	Quad-constellation multi-signal for L1 and L5 GNSS	Camera	Up to 108MP in single camera mode, Single-camera 32MP @30fps	Video	4K 30fps encoding and decoding	Display	Full HD+@120Hz	Memory	LPDDR4x	Storage	UFS v2.2	Process	5nm
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<p>plurality of network stations being interconnected via a plurality of communication channels for communicating data packages between the functional blocks,</p>	<p>The Exynos SoC utilizes Arteris network on chip interconnect technology, and/or a derivative thereof, (collectively, the “Arteris NoC”) as a data communication network:</p> <div data-bbox="472 370 1213 1284">  <p>The screenshot shows the Samsung logo at the top, followed by the text: "Samsung uses Arteris FlexNoC IP in its Samsung Exynos mobile phone applications processors, digital baseband modems, 4K SUHD TVs and Artik IoT modules." Below this text is a red-bordered button with the text "LEARN MORE »".</p> </div> <p>https://web.archive.org/web/20210514110614/https://www.arteris.com/customers</p>


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	<p style="text-align: center;">Arteris IP FlexNoC® Interconnect Licensed by Samsung's System LSI Business for Digital TV Chips</p> <p style="text-align: center;">by Kurt Shuler, on April 23, 2019</p> <p>CAMPBELL, Calif. –April 23, 2019– Arteris IP, the world's leading supplier of innovative, silicon-proven network-on-chip (NoC) interconnect semiconductor intellectual property, today announced that Samsung's System LSI Business has renewed multiple Arteris IP FlexNoC Interconnect licenses for use in multiple high-performance digital TV (DTV) processing chips utilizing Samsung's latest semiconductor technology process nodes.</p> <p>“Over many years, FlexNoC interconnect IP has helped us accelerate implementation of our digital TV chip designs on our latest semiconductor process nodes. This core interconnect technology is required to develop complex and highly optimized chips in a predictable, low-risk fashion.”</p> <p style="text-align: center;">SAMSUNG</p> <p style="text-align: center;"><i>Jaeyoul Lee, Vice President, Samsung Electronics</i></p> <p>Samsung first licensed FlexNoC interconnect IP in 2010. Since then, Samsung has used Arteris interconnect IP to enable complex SoC architectures in chips like the Exynos mobile processors and other electronic systems.</p> <p>https://www.arteris.com/press-releases/samsung-lsi-dtv-arteris-ip-flexnoc</p>

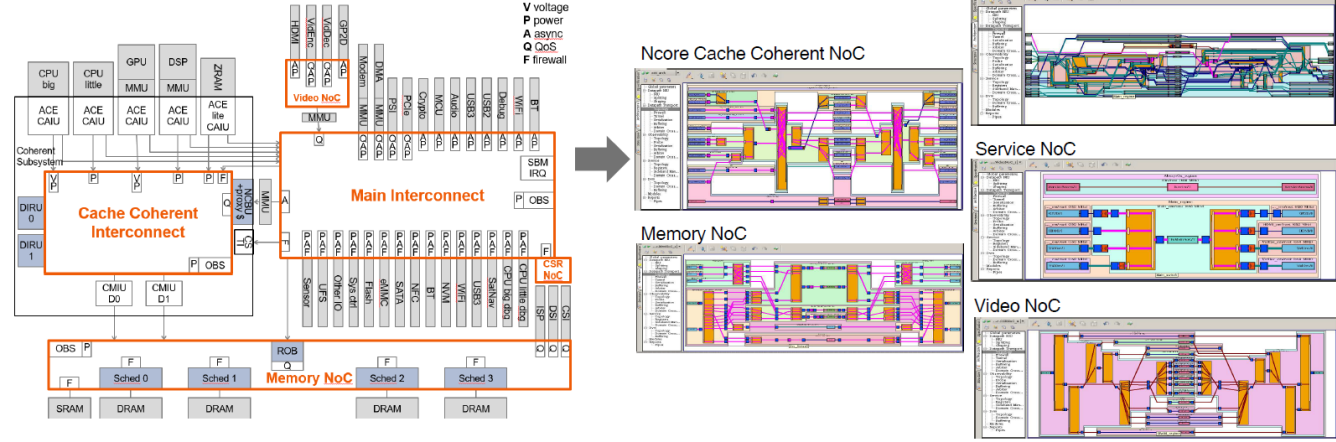
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	<p style="text-align: center;">Arteris Interconnect IP Solution Selected by Samsung for Mobile SoC Deployment</p> <p style="text-align: center;">by Kurt Shuler, on November 02, 2010</p> <p>Network-on-Chip (NoC) interconnect technology leader enables higher performance and more cost effective designs for mobile phone systems-on-chip (SoCs)</p> <p>SUNNYVALE, California — November 2, 2010 — Arteris, Inc., a leading supplier of on-chip interconnect IP solutions, today announced that Samsung Electronics Co., Ltd., has selected Arteris' interconnect solutions for multiple chips within Samsung's mobile SOC products. Samsung chose Arteris interconnect IP to support the high speed inter-chip communication requirements in next generation mobile SOC products.</p> <p>“<i>The Arteris interconnect IP offers us a convenient solution to handle the high speed communication needed between our SoC and external modem IC. Our customers will benefit from the lower BOM cost and power consumption as a result of this IP. We look forward to Arteris' interconnect IP helping us shorten development schedules and lower risks associated with compatibility.</i></p> <div style="text-align: right;">  </div> <p style="text-align: right;"><small>Thomas Kim, Vice President, SoC Platform Development, System LSI, Samsung Electronics</small></p> <p>https://www.arteris.com/press-releases/pr_2010_nov_02?hsLang=en-us</p>

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	<p>A large SoC, such as the Exynos SoC may include multiple classes of Arteris NoC data communication network:</p> <p>Logical Interconnect Topology Development</p> <p>FLEXNOC & NCORE INTERCONNECT IPS DEFINE ARCHITECTURES</p>  <ul style="list-style-type: none"> • ArChip16 Example: Large SoCs have multiple classes of interconnect <ul style="list-style-type: none"> – Non-coherent, Coherent, Control/Status, Observability, etc. • Ncore & FlexNoC interconnects are managed separately from IP blocks, increasing design flexibility <p>ARTERIS IP ISPD 2018, 28 March 2018 Copyright © 2018 Arteris IP 9</p> <p>See Physical Interconnect Aware Network Optimizer, http://www.ispd.cc/slides/2018/s7_2.pdf, at slide 9.</p>

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	<p>The Arteris NoC in the Exynos SoC is a data communication network comprising a plurality of network stations being interconnected via a plurality of communication channels for communicating data packages between the functional blocks.</p> <p>For example, the Arteris NoC uses Network Interface Units (NIUs) “at the boundary of the NoC” and which “connect[] IP blocks to the network”:</p> <p>11.3.1.1 Transaction Layer</p> <p>The transaction layer is compatible with bus-based transaction protocols used for on-chip communications. It is implemented in NIUs, which are at the boundary of the NoC, and translates between third-party and NTTP protocols. Most transactions require the following two-step transfers:</p> <ul style="list-style-type: none"> • A master sends request packets. • Then, the slave returns response packets. <p>As shown in Figure 11.1, requests from an initiator are sent through the master NIU’s transmit port, Tx, to the NoC request network, where they are routed to the corresponding slave NIU. Slave NIUs, upon reception of request packets</p>

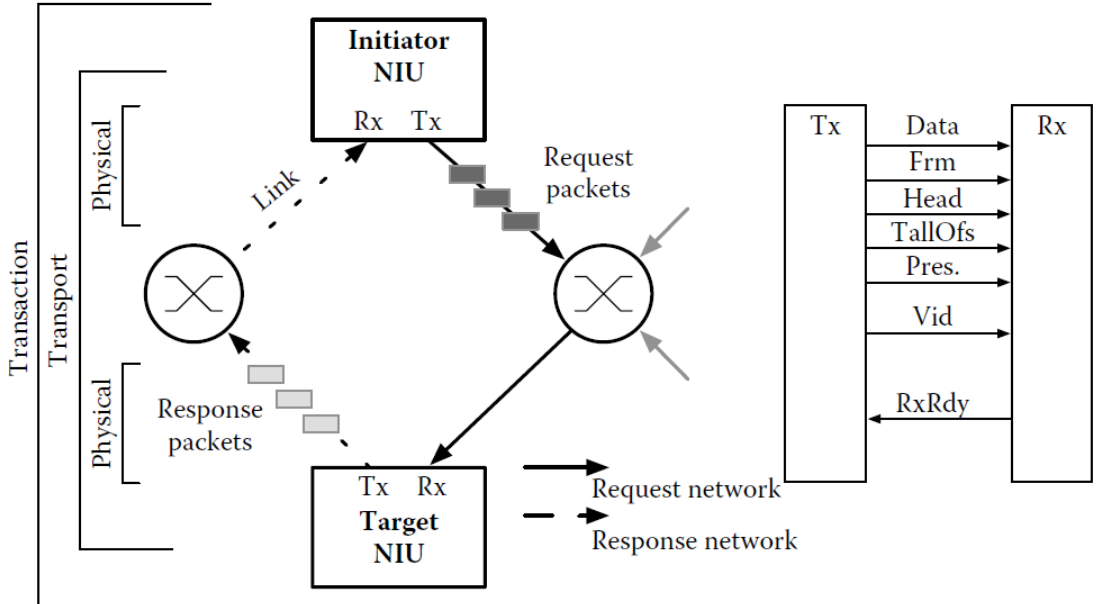
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	<p>on their receive ports, Rx, translate requests so that they comply with the protocol used by the target third-party IP node. When the target node responds, returning responses are again converted by the slave NIU into appropriate response packets, then delivered through the slave NIU’s Tx port to the response network. The network then routes the response packets to the requesting master NIU, which forwards them to the initiator. At the transaction level, NIUs enable multiple protocols to coexist within the same NoC. From the point of view of the NTTP modules, different third-party protocols are just packets moving back and forth across the network.</p> <p>See Networks-On-Chips Theory and Practice, https://vdoc.pub/download/networks-on-chips-theory-and-practice-embedded-multi-core-systems-6f26qivv11f0, at 311, 312-313; <i>see id</i> at 308 (explaining that Chapter 11 of this book describes the function of the Arteris NoC: “In this chapter we will present an MPSoC platform [...] using Arteris NoC as communication infrastructure.”).</p> <p>As a further illustration, in the Arteris NoC, “[a]n NTTP transaction is typically made of request packets, traveling through the request network between the master and the slave NIUs, and response packets that are exchanged between a slave NIU and a master NIU through the response network.... Transactions are handed off to the transport layer, which is responsible for delivering packets between endpoints of the NoC (using links, routers, muxes, rated adapters, FIFOs, etc.). Between NoC components, packets are physically transported as cells across various interfaces, a cell being a basic data unit being transported. This is illustrated in Figure 11.1, with one master and one slave node, and one router in the request and response path.”</p>

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	 <p>FIGURE 11.1 NTTP protocol layers mapped on NoC units and Media Independent NoC Interface—MINI.</p> <p>See Networks-On-Chips Theory and Practice, https://vdoc.pub/download/networks-on-chips-theory-and-practice-embedded-multi-core-systems-6f26qivv11f0, at 312.</p>

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<p>each data package comprising N data elements including a data element comprising routing information for the network stations, N being an integer of at least two,</p>	<p>In the Arteris NoC utilized by the Exynos SoC, each data package comprising N data elements including a data element comprising routing information for the network stations, N being an integer of at least two, either literally or under the doctrine of equivalents.</p> <p>For example, the “Arteris NTTP protocol is packet-based” and the packets, which have “header and necker cells [that] contain information relative to routing, payload size, packet type, and the packet target address,” are “transported to other parts of the NoC to accomplish the transactions that are required by foreign IP nodes”:</p> <p>11.3.1.2 Transport Layer</p> <p>The Arteris NTTP protocol is packet-based. Packets created by NIUs are transported to other parts of the NoC to accomplish the transactions that are required by foreign IP nodes. All packets are comprised of cells: a header cell, an optional necker cell, and possibly one or more data cells (for packet definition see Figure 11.2; further descriptions of the packet can be found in the next subsection). The header and necker cells contain information relative to routing, payload size, packet type, and the packet target address. Formats for request packets and response packets are slightly different, with the key difference being the presence of an additional cell, the necker, in the request packet to provide detailed addressing information to the target.</p> <p>See Networks-On-Chips Theory and Practice, https://vdoc.pub/download/networks-on-chips-theory-and-practice-embedded-multi-core-systems-6f26qivv11f0, at 313.</p> <p>As yet a further illustration, packets in the Arteris NoC are “delivered as words that are sent along links and “[o]ne link (represented in Figure 11.1) defines the following signals”:</p>

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maximum cell-width (header, necker, and data cell) and the link-width. One link (represented in [Figure 11.1](#)) defines the following signals:

- **Data**—Data word of the width specified at design-time.
- **Frm**—When asserted high, indicates that a packet is being transmitted.
- **Head**—When asserted high, indicates the current word contains a packet header. When the link-width is smaller than single (SGL), the header transmission is split into several word transfers. However, the Head signal is asserted during the first transfer only.
- **TailOfs**—Packet tail: when asserted high, indicates that the current word contains the last packet cell. When the link-width is smaller than single (SGL), the last cell transmission is split into several word transfers. However, the Tail signal is asserted during the first transfer only.
- **Pres.**—Indicates the current priority of the packet used to define preferred traffic class (or Quality of Service). The width is fixed during the design time, allowing multiple pressure levels within the same NoC instance (bits 3–5 in [Figure 11.2](#)).
- **Vld**—Data valid: when asserted high, indicates that a word is being transmitted.
- **RxRdy**—Flow control: when asserted high, the receiver is ready to accept word. When de-asserted, the receiver is busy.

This signal set, which constitutes the Media Independent NoC Interface (MINI), is the foundation for NTTP communications.

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	<p><i>Id.</i> at 313-314.</p> <p>As a further example, the packets sent in the Arteris NoC are “composed of cells that are organized into fields, with each field carrying specific information”:</p> <table><tr><th>Field</th><th>Size</th><th>Function</th></tr><tr><td>Opcode</td><td>4 bits/3 bits</td><td>Packet type: 4 bits for requests, 3 bits for responses</td></tr><tr><td>MstAddr</td><td>User Defined</td><td>Master address</td></tr><tr><td>SlvAddr</td><td>User Defined</td><td>Slave address</td></tr><tr><td>SlvOfs</td><td>User Defined</td><td>Slave offset</td></tr><tr><td>Len</td><td>User Defined</td><td>Payload length</td></tr><tr><td>Tag</td><td>User Defined</td><td>Tag</td></tr><tr><td>Prs</td><td>User defined (0 to 2)</td><td>Pressure</td></tr><tr><td>BE</td><td>0 or 4 bits</td><td>Byte enables</td></tr><tr><td>CE</td><td>1 bit</td><td>Cell error</td></tr><tr><td>Data</td><td>32 bits</td><td>Packet payload</td></tr><tr><td>Info</td><td>User Defined</td><td>Information about services supported by the NoC</td></tr><tr><td>Err</td><td>1 bit</td><td>Error bit</td></tr></table>	Field	Size	Function	Opcode	4 bits/3 bits	Packet type: 4 bits for requests, 3 bits for responses	MstAddr	User Defined	Master address	SlvAddr	User Defined	Slave address	SlvOfs	User Defined	Slave offset	Len	User Defined	Payload length	Tag	User Defined	Tag	Prs	User defined (0 to 2)	Pressure	BE	0 or 4 bits	Byte enables	CE	1 bit	Cell error	Data	32 bits	Packet payload	Info	User Defined	Information about services supported by the NoC	Err	1 bit	Error bit
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	StartOfs	2 bits	Start offset
	StopOfs	2 bits	Stop offset
	WrpSize	4 bits	Wrap size
	Rsv	Variable	Reserved
	CtlId	4 bits/3 bits	Control identifier, for control packets only
	CtlInfo	Variable	Control information, for control packets only
	EvtId	User defined	Event identifier, for event packets only

35

29 28

25 24

15 14

5 4 3

0

Header	Info		Len	Master Address		Slave Address		Prs	Opcode		
Necker	Tag		Err	Slave offset						StartOfs	StopOfs
Data	BE	Data Byte		BE	Data Byte		BE	Data Byte		BE	Data Byte
Data	BE	Data Byte		BE	Data Byte		BE	Data Byte		BE	Data Byte

32 31 30

27 26

20 19

14 13

5 4 3

0

Header	Rsv	Len	Info		Tag	Master Address		Prs	Opcode		
Data	CE	Data									
Data	CE	Data									

FIGURE 11.2
NTTP packet structure.

Networks-On-Chips Theory and Practice, <https://vdoc.pub/download/networks-on-chips-theory-and-practice-embedded-multi-core-systems-6f26qivv11f0>, at 313, 314-315.

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<p>the plurality of network stations comprising a plurality of data routers and a plurality of network interfaces, each of the data routers being coupled to a functional block via a network interface,</p>	<p>In the Arteris NoC utilized by the Exynos SoC, the plurality of network stations comprise a plurality of data routers and a plurality of network interfaces, each of the data routers being coupled to a functional block via a network interface, either literally or under the doctrine of equivalents.</p> <p>For example, the Arteris NoC uses Network Interface Units (NIUs) “at the boundary of the NoC” and which “connect[] IP blocks to the network”:</p> <p>11.3.1.1 Transaction Layer</p> <p>The transaction layer is compatible with bus-based transaction protocols used for on-chip communications. It is implemented in NIUs, which are at the boundary of the NoC, and translates between third-party and NTTP protocols. Most transactions require the following two-step transfers:</p> <ul style="list-style-type: none"> • A master sends request packets. • Then, the slave returns response packets. <p>As shown in Figure 11.1, requests from an initiator are sent through the master NIU’s transmit port, Tx, to the NoC request network, where they are routed to the corresponding slave NIU. Slave NIUs, upon reception of request packets</p>

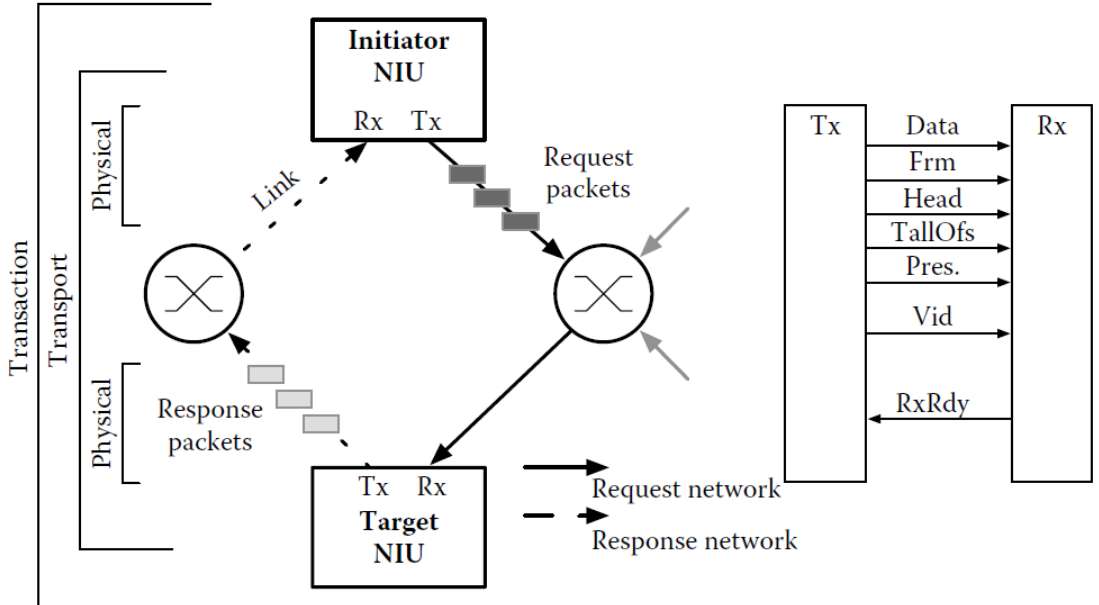
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	<p>on their receive ports, Rx, translate requests so that they comply with the protocol used by the target third-party IP node. When the target node responds, returning responses are again converted by the slave NIU into appropriate response packets, then delivered through the slave NIU’s Tx port to the response network. The network then routes the response packets to the requesting master NIU, which forwards them to the initiator. At the transaction level, NIUs enable multiple protocols to coexist within the same NoC. From the point of view of the NTTP modules, different third-party protocols are just packets moving back and forth across the network.</p> <p>See Networks-On-Chips Theory and Practice, https://vdoc.pub/download/networks-on-chips-theory-and-practice-embedded-multi-core-systems-6f26qivv11f0, at 311, 312-313.</p> <p>As a further illustration, in the Arteris NoC, “[a]n NTTP transaction is typically made of request packets, traveling through the request network between the master and the slave NIUs, and response packets that are exchanged between a slave NIU and a master NIU through the response network.... Transactions are handed off to the transport layer, which is responsible for delivering packets between endpoints of the NoC (using links, routers, muxes, rated adapters, FIFOs, etc.). Between NoC components, packets are physically transported as cells across various interfaces, a cell being a basic data unit being transported. This is illustrated in Figure 11.1, with one master and one slave node, and one router in the request and response path.”</p>

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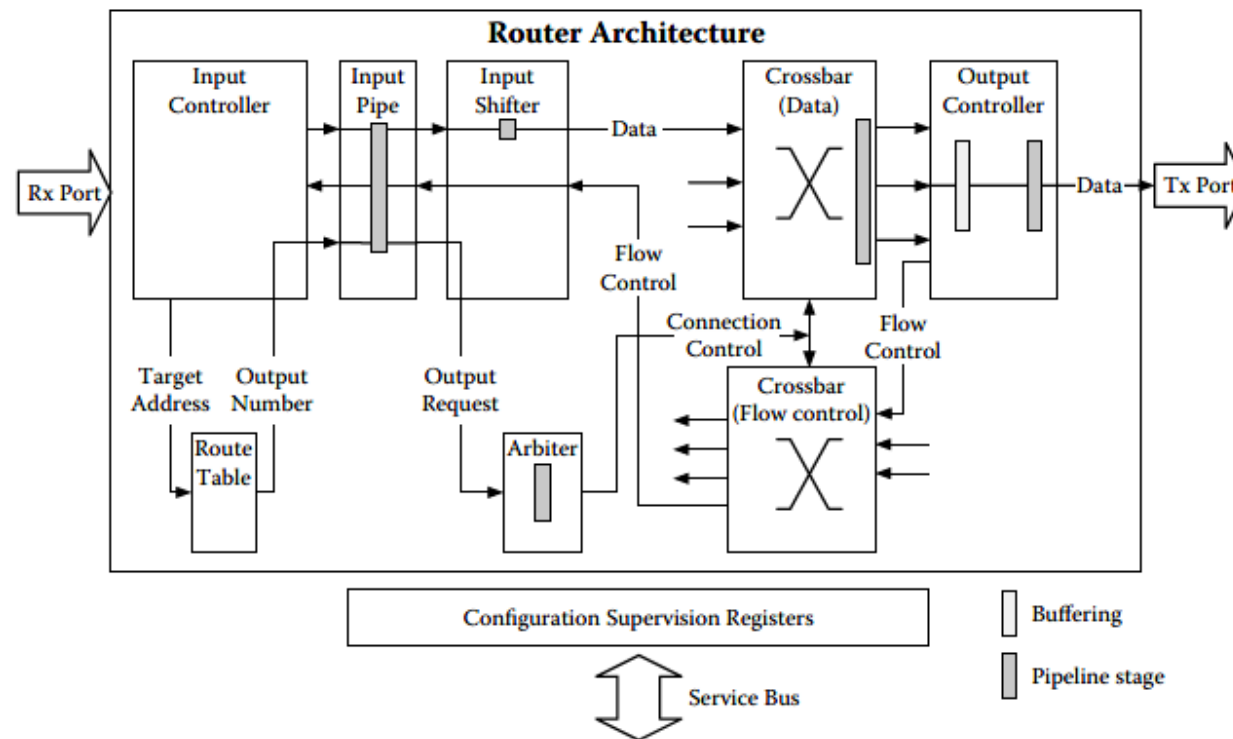
re'2893 Patent Claim	Samsung Exynos 1280 System on Chip ¹
	 <p>FIGURE 11.1 NTTP protocol layers mapped on NoC units and Media Independent NoC Interface—MINI.</p> <p>See Networks-On-Chips Theory and Practice, https://vdoc.pub/download/networks-on-chips-theory-and-practice-embedded-multi-core-systems-6f26qivv11f0, at 312.</p> <p>As a further illustration of the routers in the Arteris NoC:</p>

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11.3.3.2 Routing

The switch extracts the destination address and possibly the scattering information from the incoming packet header and necker cells, and then selects an output port accordingly. For a request switch, the destination address is the slave address and the scattering information is the master address

**FIGURE 11.6**

Packet transportation unit: Router architecture.

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	<p>As a further illustration of the network interfaces in the Arteris NoC:</p> <p>11.3.2.1 Initiator NIU Units</p> <p>Initiator NIU units (the architecture of the AHB initiator is given in Figure 11.4) enable connection between an AMBA-AHB master IP and the NoC. It translates AHB transactions into an equivalent NTTP packet sequence, and transports requests and responses to and from a target NIU, that is, slave IP (slave can be any of the supported protocols). The AHB-to-NTTP unit instantiates a Translation Table for address decoding. This table receives 32-bit AHB addresses from the NIU and returns the packet header and necker information that is needed to access the NTTP address space: Slave address, Slave offset, Start offset, and the coherency size (see Figure 11.2). Whenever the AHB address does not fit the predefined decoding range, the table asserts an error signal that sets the error bit of the corresponding NTTP request packet, for further error handling by the NoC. The translation table is fully user-defined at design time: it must first be completed with its own hardware parameters, then passed to the NIU.</p> <p>Networks-On-Chips Theory and Practice, https://vdoc.pub/download/networks-on-chips-theory-and-practice-embedded-multi-core-systems-6f26qivv11f0, at 317.</p>

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	<p>11.3.2.2 Target NIU Units</p> <p>Target NIU units enable connection of a slave IP to the NoC by translating NTTP packet sequences into equivalent packet transactions, and transporting requests and responses to and from targets (the architecture of the AHB Target NIU is given in Figure 11.5). For the AHB target NIU, the AHB address space is mapped from the NTTP address space using the slave offset, the start/stop offset, and the slave address fields, when applicable (from the header of the request packet, Figure 11.2). The AHB address bus is always</p> <p><i>Id.</i> at 318.</p>
the data communication network comprising a first network station and a second network station interconnected through a first communication channel, the data communication	<p>In the Arteris NoC utilized in the Exynos SoC, the data communication network comprising a first network station and a second network station interconnected through a first communication channel, the data communication network further comprising M*N data storage elements, M being a positive integer, either literally or under the doctrine of equivalents.</p> <p>For example, the Arteris NoC uses Network Interface Units (NIUs) “at the boundary of the NoC” and which “connect[] IP blocks to the network”:</p>

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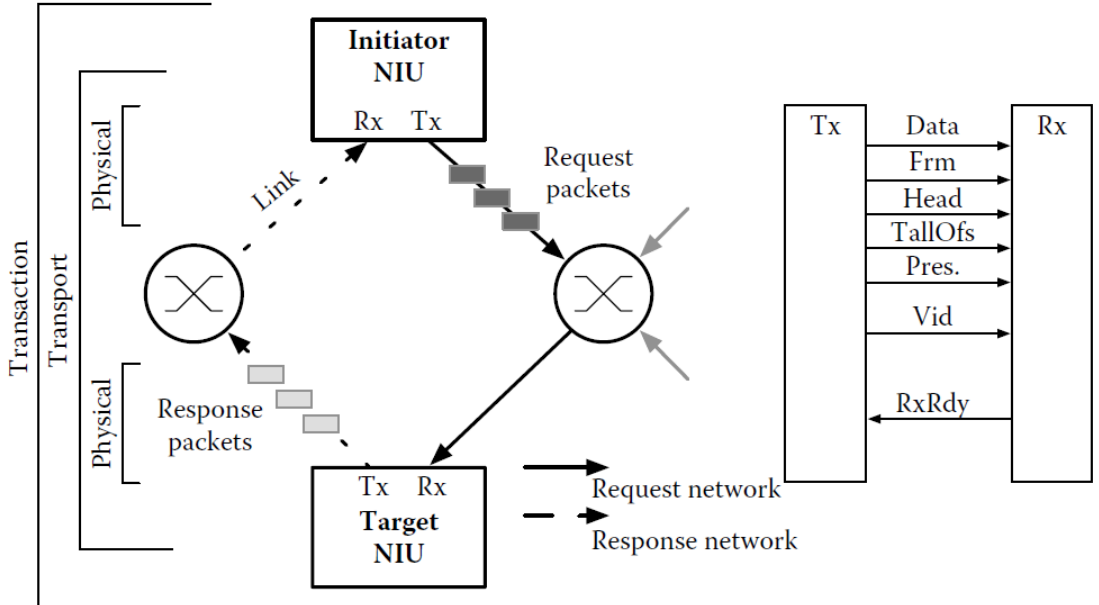
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network further comprising M*N data storage elements, M being a positive integer,	<p>11.3.1.1 Transaction Layer</p> <p>The transaction layer is compatible with bus-based transaction protocols used for on-chip communications. It is implemented in NIUs, which are at the boundary of the NoC, and translates between third-party and NTTP protocols. Most transactions require the following two-step transfers:</p> <ul style="list-style-type: none"> • A master sends request packets. • Then, the slave returns response packets. <p>As shown in Figure 11.1, requests from an initiator are sent through the master NIU's transmit port, Tx, to the NoC request network, where they are routed to the corresponding slave NIU. Slave NIUs, upon reception of request packets on their receive ports, Rx, translate requests so that they comply with the protocol used by the target third-party IP node. When the target node responds, returning responses are again converted by the slave NIU into appropriate response packets, then delivered through the slave NIU's Tx port to the response network. The network then routes the response packets to the requesting master NIU, which forwards them to the initiator. At the transaction level, NIUs enable multiple protocols to coexist within the same NoC. From the point of view of the NTTP modules, different third-party protocols are just packets moving back and forth across the network.</p>

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	<p>See Networks-On-Chips Theory and Practice, https://vdoc.pub/download/networks-on-chips-theory-and-practice-embedded-multi-core-systems-6f26qivv11f0, at 311, 312-313.</p> <p>As a further illustration, in the Arteris NoC, “[a]n NTTP transaction is typically made of request packets, traveling through the request network between the master and the slave NIUs, and response packets that are exchanged between a slave NIU and a master NIU through the response network.... Transactions are handed off to the transport layer, which is responsible for delivering packets between endpoints of the NoC (using links, routers, muxes, rated adapters, FIFOs, etc.). Between NoC components, packets are physically transported as cells across various interfaces, a cell being a basic data unit being transported. This is illustrated in Figure 11.1, with one master and one slave node, and one router in the request and response path.”</p>

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	 <p>FIGURE 11.1 NTTP protocol layers mapped on NoC units and Media Independent NoC Interface—MINI.</p> <p>See Networks-On-Chips Theory and Practice, https://vdoc.pub/download/networks-on-chips-theory-and-practice-embedded-multi-core-systems-6f26qivv11f0, at 312.</p> <p>As a further example, a “delay pipeline is automatically inserted in the input controller to keep data and routing information in phase” and an input pipe “introduces a one-word-deep FIFO”:</p>

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	<p>Depending on the kind of routing table chosen, more than one cycle may be required to make a decision. A delay pipeline is automatically inserted in the input controller to keep data and routing information in phase, thus guaranteeing one-word-per-cycle peak throughput. Routing tables select the output port that a given packet must take. The route decision is based on the</p> <p>* * *</p> <p>The input pipe is optional and may be inserted individually for each input port. It introduces a one-word-deep FIFO between the input controller and the crossbar and can help timing closure, although at the expense of one supplementary latency cycle.</p> <p>See Networks-On-Chips Theory and Practice, https://vdoc.pub/download/networks-on-chips-theory-and-practice-embedded-multi-core-systems-6f26qivv11f0, at 322.</p> <p>As a further example, the crossbar may have pipeline storage elements and the output controller contains a FIFO storage element “with as many words as there are date pipelined in the crossbar”:</p>

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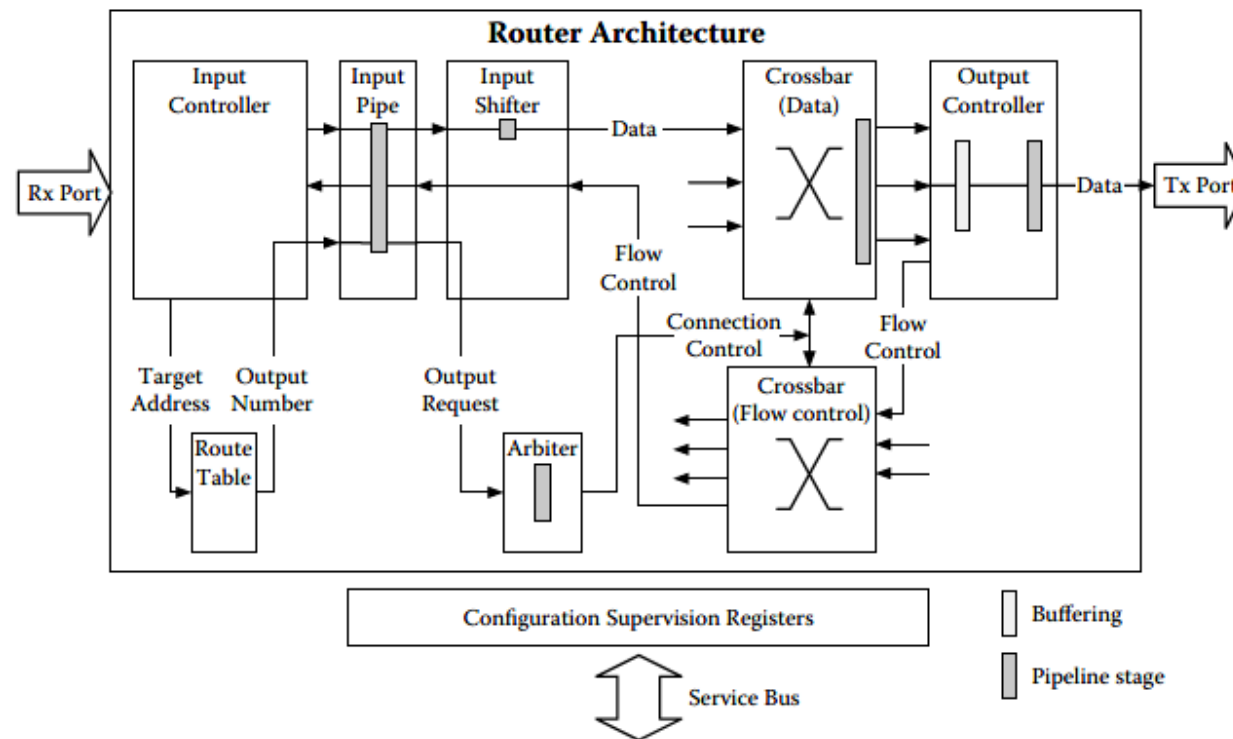
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	<p>The crossbar implements datapath connection between inputs and outputs. It uses the connection matrix produced by the arbiter to determine which connections must be established. It is equivalent to a set of m muxes (one per output port), each having n inputs (one per input port). If necessary, the crossbar can be pipelined to enhance timing. The number of pipeline stages can be as high as $\max(n, m)$.</p> <p>The output controller constructs the output stream. It is also responsible for compensating crossbar latency. It contains a FIFO with as many words as there are data pipelined in the crossbar. FIFO flow control is internally managed with a credit mechanism. Although FIFO is typically empty, should the output port become blocked, it contains enough buffering to flush the crossbar. When necessary for timing reasons, a pipeline stage can be introduced at the output of the controller.</p> <p><i>Id.</i> at 323.</p> <p>The buffering and pipeline stages are shown in the following depiction of the router architecture of the Arteris NoC:</p>

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11.3.3.2 Routing

The switch extracts the destination address and possibly the scattering information from the incoming packet header and necker cells, and then selects an output port accordingly. For a request switch, the destination address is the slave address and the scattering information is the master address

**FIGURE 11.6**

Packet transportation unit: Router architecture.

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	<p><i>Id.</i> at 320.</p> <p>As another example, the “fwdPipe” parameter “introduces a true pipeline register on the forward signals” and “inserts the DFFs required to register a full data word as well as with control signals, and a cycle delay is inserted for packets traveling this path”:</p> <p>get frequency, process, or floor plan. The opportunity to break long paths is present on most MINI transmission ports, and is controlled through a parameter named fwdPipe: when set, this parameter introduces a true pipeline register on the forward signals, and effectively breaks the forward path. The parameter inserts the DFFs required to register a full data word as well as with control signals, and a cycle delay is inserted for packets traveling this path.</p> <p><i>Id.</i> at 323-324.</p>
the data communication introducing a delay of M*N cycles on the first communication channel when the data communication	<p>In the Arteris NoC utilized in the Exynos SoC, the data communication introducing a delay of M*N cycles on the first communication channel when the data communication network identifies the first communication channel as having a data transfer delay exceeding a predefined delay threshold, either literally or under the doctrine of equivalents.</p> <p>For example, a “delay pipeline is automatically inserted in the input controller to keep data and routing information in phase” and an input pipe “introduces a one-word-deep FIFO”:</p>

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<p>network identifies the first communication channel as having a data transfer delay exceeding a predefined delay threshold.</p>	<p>Depending on the kind of routing table chosen, more than one cycle may be required to make a decision. A delay pipeline is automatically inserted in the input controller to keep data and routing information in phase, thus guaranteeing one-word-per-cycle peak throughput. Routing tables select the output port that a given packet must take. The route decision is based on the</p> <p>* * *</p> <p>The input pipe is optional and may be inserted individually for each input port. It introduces a one-word-deep FIFO between the input controller and the crossbar and can help timing closure, although at the expense of one supplementary latency cycle.</p> <p>See Networks-On-Chips Theory and Practice, https://vdoc.pub/download/networks-on-chips-theory-and-practice-embedded-multi-core-systems-6f26qivv11f0, at 322.</p> <p>As a further example, the crossbar may have pipeline storage elements and the output controller contains a FIFO storage element “with as many words as there are date pipelined in the crossbar”:</p>

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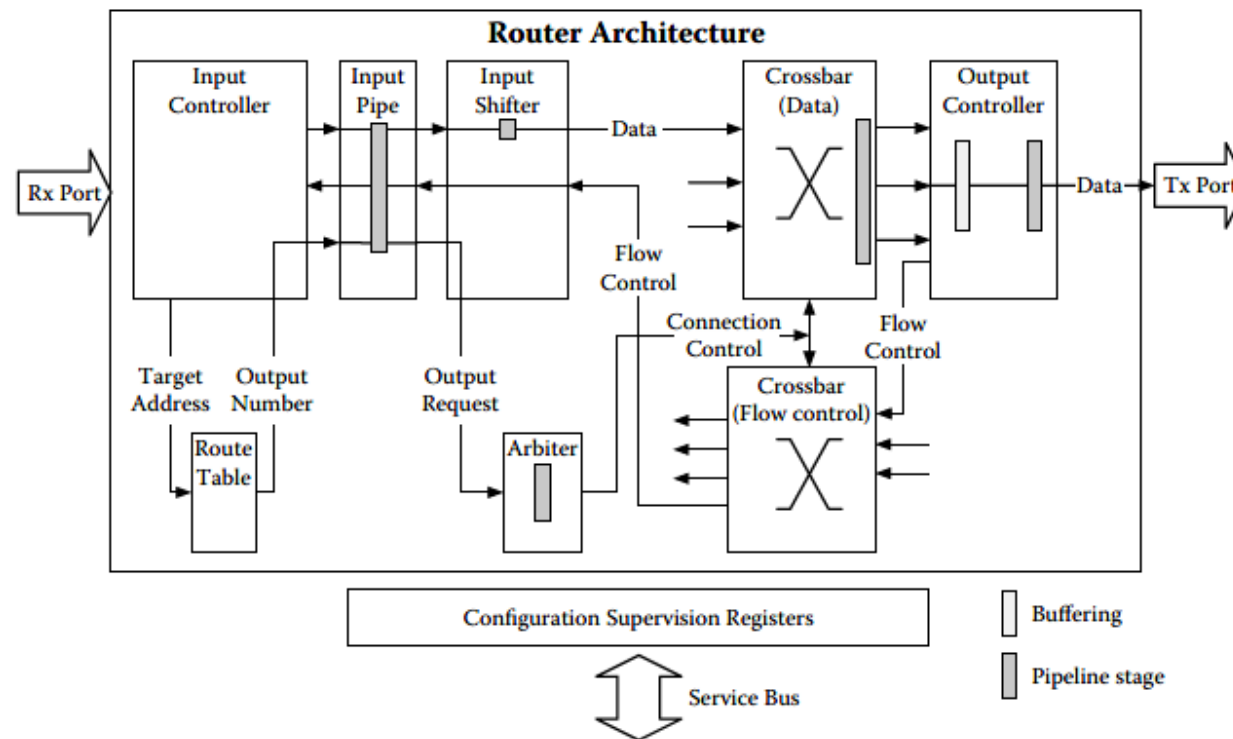
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	<p>The crossbar implements datapath connection between inputs and outputs. It uses the connection matrix produced by the arbiter to determine which connections must be established. It is equivalent to a set of m muxes (one per output port), each having n inputs (one per input port). If necessary, the crossbar can be pipelined to enhance timing. The number of pipeline stages can be as high as $\max(n, m)$.</p> <p>The output controller constructs the output stream. It is also responsible for compensating crossbar latency. It contains a FIFO with as many words as there are data pipelined in the crossbar. FIFO flow control is internally managed with a credit mechanism. Although FIFO is typically empty, should the output port become blocked, it contains enough buffering to flush the crossbar. When necessary for timing reasons, a pipeline stage can be introduced at the output of the controller.</p> <p><i>Id.</i> at 323.</p> <p>The buffering and pipeline stages are shown in the following depiction of the router architecture of the Arteris NoC:</p>

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**FIGURE 11.6**

Packet transportation unit: Router architecture.


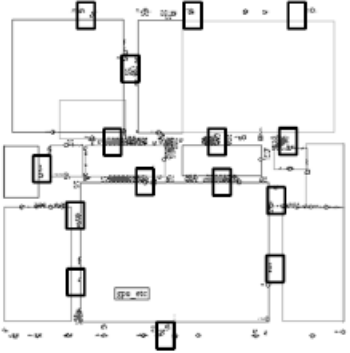

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	<p><i>Id.</i> at 320.</p> <p>As another example, the “fwdPipe” parameter “introduces a true pipeline register on the forward signals” and “inserts the DFFs required to register a full data word as well as with control signals, and a cycle delay is inserted for packets traveling this path”:</p> <p>get frequency, process, or floor plan. The opportunity to break long paths is present on most MINI transmission ports, and is controlled through a parameter named fwdPipe: when set, this parameter introduces a true pipeline register on the forward signals, and effectively breaks the forward path. The parameter inserts the DFFs required to register a full data word as well as with control signals, and a cycle delay is inserted for packets traveling this path.</p> <p><i>Id.</i> at 323-324.</p> <p>As another example, pipelines may be automatically inserted by the Arteris NoC to close timing:</p>

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	<div data-bbox="499 305 1371 959"> <h3>Adding Pipelines Automatically</h3> <ul style="list-style-type: none"> ○ Evaluate all timing arcs in the NoC interconnect ○ Distance and logic depth dictate number of pipeline stages ○ Placement of the NoC units is predicted by FlexNoC <p>  = New pipelines inserted by FlexNoC Physical to close timing </p>  <p>Copyright © 2015 Arteris 14 </p> </div> <p>Using SoC Interconnect IPs to Improve Physical Layout, http://mpsoc-forum.org/archive/2015/slides/45B-Charles%20Janac.pdf, at slide 14.</p> <p>As a further illustration, the Arteris NoC includes pipelining for distance spanning when traveling “~6mm” has a propagation delay of “~400ps/mm”, requiring at least “2400ps to span the Distance”; thus requiring “at least 3 pipeline stages and 4 clock cycles to meet timing.”</p>

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	<div data-bbox="525 308 1722 365" data-label="Section-Header"> <h2 style="color: orange;">Wire Delays – Can't Cross a Chip in 1 Clock Cycle</h2> </div> <div data-bbox="525 373 1407 406" data-label="Text"> <p>PHYSICAL DISTANCE DICTATES THE NUMBER OF PIPELINE STAGES</p> </div> <div data-bbox="672 438 882 682" data-label="Figure"> </div> <div data-bbox="525 747 1512 885" data-label="List-Group"> <ul style="list-style-type: none"> • Interconnect Frequency: 1.2GHz = 833ps • Distance to travel = ~6mm • Propagation delay = ~400ps/mm in 16nm FinFET; Needs 2400ps to span the distance • Requires at least 3 pipeline stages and 4 clock cycles to meet timing </div> <div data-bbox="525 893 1806 966" data-label="Text" style="background-color: orange; color: white; padding: 5px;"> <p>Large 14nm FinFET SoC may have >6,000 pipelines with 6K factorial pipeline combinations and 60 timing parameters – Too much for human comprehension!</p> </div> <div data-bbox="1176 422 1827 787" data-label="Diagram"> </div> <div data-bbox="493 990 640 1023" data-label="Text"> <p>ARTERIS^{IP}</p> </div> <div data-bbox="1081 998 1249 1019" data-label="Text"> <p>ISPD 2018, 28 March 2018</p> </div> <div data-bbox="1617 998 1837 1019" data-label="Text"> <p>Copyright © 2018 Arteris IP 3</p> </div> <div data-bbox="451 1047 1858 1128" data-label="Text"> <p>See Physical Interconnect Aware Network Optimizer, http://www.ispd.cc/slides/2018/s7_2.pdf, at slide 3.</p> </div>